Stabilization Concepts for a Spherical Planetary Entry Probe Configuration

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Theme

A SPHERE is a desirable configuration to perform entry science measurements for a simple planetary entry probe mission due its drag characteristics; however spheres are dynamically unstable. The purpose of this synoptic is to evaluate proven subsonic aerodynamic stability concepts for a sphere for application to supersonic flow to determine the optimum sphere stability concept for re-entry.

Contents

The concept of a spherical planetary entry probe configuration for atmospheric definition of a planet has been proposed by Seiff and Reese.[1] Seiff and Reese have shown that a spherical configuration offers advantages[1] over other entry configurations to reconstruct the atmospheric structure of a planet due to its drag characteristics.

It has been shown by Short[2] that ballasted spheres with a 14% static margin are dynamically unstable from subsonic to hypersonic flow based on ballistic range data. Short suggests that instability is due primarily to a fluctuating/variable asymmetric flow separation point (Fig. 1). The fluctuating separation point is nonsymmetric and produces differences in the pressure distribution around the sphere which leads to an unsteady normal force. Accordingly, a ballasted sphere is an unacceptable configuration to perform the mission of a simple probe without a stability augmentation device.

Two basic concepts have been pursued by experiments in the past to stabilize spheres in subsonic flow—wake stabilizer devices, and flow separation devices. Although several workable wake stabilizer concepts exist to stabilize spheres in subsonic flow (fins, drogues, and a hula skirt) none are practical for supersonic flow due to heating, weight penalties and deployment problems. In addition, wake stabilizer devices would tend to negate any advantage of using a spherical planetary entry configuration since these modified configurations would not have the same aerodynamic characteristics as a sphere. Flow separation devices tend to get at the root of the stability problem—the variable asymmetric flow separation point. It has been shown[3-5] that the dynamic instability can be eliminated in subsonic flow by fixing the flow separation point with either the torus sphere or the sphere-step concept (Fig. 2). It is hypothesized that both subsonic flow separation stability concepts would also work in supersonic flow by providing a definite fixed separation point for the boundary layer flow to separate. However, the sphere-step appears to offer the most viable solution for sphere stability in supersonic flow. This is because the sphere with a torus stabilizing ring would present a severe heating problem for the ring in supersonic flow, and would require additional ablation material for the ring resulting in a weight penalty. In addition, the torus sphere would not be aerodynamically similar to a sphere. Conversely the sphere-step should retain the aerodynamic advantages of a spherical entry body, and require no additional ablation material and incur no weight penalty.

Figure 3 presents a compilation of all the available dynamic damping data for ballasted spheres and two NOL data points

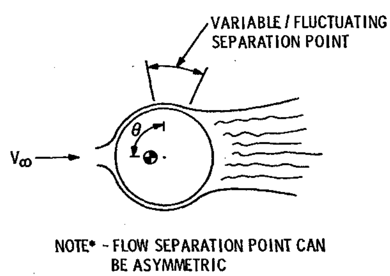

Fig. 1 Flow mechanism for ballasted sphere dynamic instability.

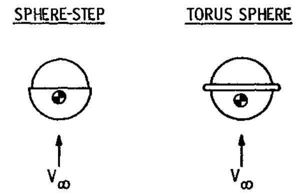

Fig. 2 Flow separation stability concepts.

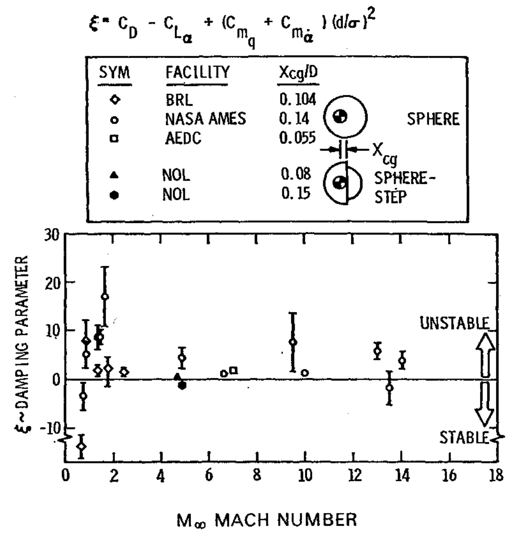

Fig. 3 Damping parameter data for ballasted spheres and sphere-step models.

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Index categories: Entry Vehicles and Landers; Entry Vehicle Dynamics and Control.

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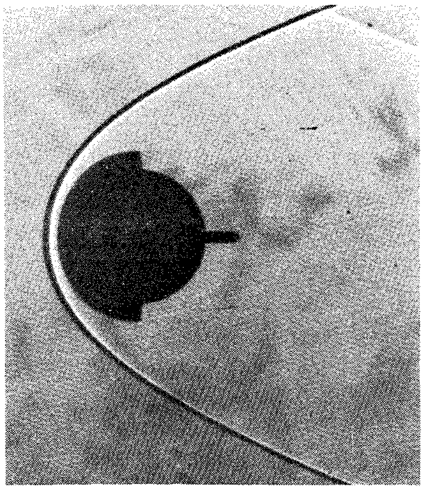

Fig. 4 Sphere-step shadowgraph showing flow separates at step; NOL data; shot #1618, $M_\infty = 4.87$, $Re_d = 1.08 \times 10^6$.

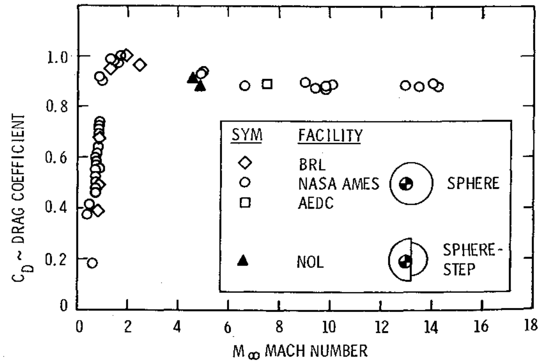

Fig. 6 Drag data for ballasted spheres and sphere-step models.

for a sphere-step configuration. Several points are significant. First, the bulk of the data shows that a ballasted sphere configuration is dynamically unstable from subsonic through hypersonic flow for static margins ranging from 5% to 14% D (3 out of 18 data points are stable; reason unknown). Second, the sphere-step configuration is dynamically stable at $M_\infty = 4.7$ for a static margin of 15% D ($\xi = +4.3$) as compared with a ballasted sphere which is unstable for the same Mach number and static margin ($\xi = -1.25$). Third, the dynamic stability parameter appears to be a function of c.g. location for the sphere-step becoming unstable at a static margin of 8% D. However, packaging studies conducted at GE on a modified sphere-step configuration have indicated static margins on the order of ~15% D or greater. Hence, it is tentatively concluded that a dynamically stable sphere entry vehicle is feasible with the step concept.

It should be noted that the sphere-step configuration tested at NOL had a step-to-sphere radius ratio of ~0.20. It is believed that a smaller step, perhaps ~10% R would produce the same result of stabilizing a sphere. Figure 4 shows a shadowgraph of the sphere-step which illustrates that the step could be reduced and not cause flow reattachment at this test condition. It is considered that the criteria for stability is simply that the step must be large enough to a) provide a definite flow separation point, b) not be buried within the boundary layer, and c) to assure that flow reattachment does not occur on the afterbody. Figure 5 shows a shadowgraph of a ballasted sphere (dynamically unstable) in which the flow stays attached and separates past the maximum diameter.

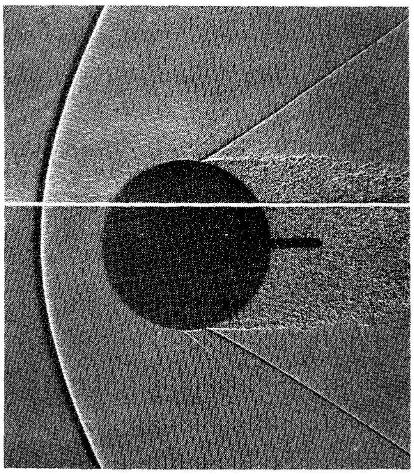

Fig. 5 Sphere shadowgraph showing flow stays attached past the maximum diameter; BRL data: round no. 7292, $M_\infty = 1.32$.

A comparison of the available drag data for ballasted spheres and the sphere-step data is presented in Fig. 6 as a function of Mach number. The sphere-step data are in excellent agreement with the sphere data indicating that the presence of the step does not alter the basic drag characteristic of the sphere at $M_\infty \approx 4.7$.

The sphere-step concept appears to offer a viable solution to the problem of stabilizing a spherical planetary entry configuration. The sphere-step concept has been demonstrated to be dynamically stable in both subsonic and supersonic flow and thus provides a unique configuration for simple planetary entry probes. The sphere-step configuration should have all the aerodynamic advantages of a sphere for planetary entry applications without the basic disadvantage of a sphere, the dynamic instability. Further studies are required to optimize the step size and assess the sphere-step concept throughout the Mach number, angle of attack, and Reynolds number range expected on the planets.

References

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[2] Short, B. J. "Dynamic Flight Behavior of a Ballasted Sphere at Mach Numbers from 0.4 to 14.5," TND-4198, Oct. 1967, NASA.

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